Design Guidelines for Slope Tapered Pipe Culverts

January 31, 2000

The purpose of using slope tapered pipe culverts is to reduce construction costs and still provide the same hydraulic capacity and upstream headwater. The concept will be used primarily on Type 1501 culverts which have concrete pipe on a relatively flat slope under the pavement and corrugated metal or polyethylene pipe down the steep foreslope of the highway embankment. The intent is to use available precast concrete pipe appurtenances and thus avoid special, costly designs by the manufacturers. This keeps the cost of material supply, and therefore total installation, lower. For example, by reducing a 48-inch pipe to a 36-inch pipe, the cost savings for a 150-foot long barrel may be $25/foot X 150' = $3750. This savings should be compared to the costs of elbows and reducers to decide if a slope tapered inlet is practical at a given site.

The culvert site normally will meet two basic requirements to qualify for a tapered inlet. The first is that the additional costs for special pipe sections are offset by the reduction in barrel costs. The second is that the site must have enough fall for the design to perform properly, typically at least four to six feet.

The culvert inlet is made large enough to keep the depth of water at the entrance within allowable limits. The slope taper section funnels the water down a steep slope and the barrel diameter decreases. The barrel section is designed to flow nearly full when carrying the design discharge. Frequently the outlet will have a letdown pipe or flume.

Design Steps

There are five basic steps for the hydraulic design a pipe culvert with a slope tapered inlet.

1. Determine the design discharge. The Iowa Runoff Chart shall be used for rural watersheds draining 1000 acres (400 hectares) or less.
2. Determine the allowable depth of water at the inlet. Typically, the Iowa DOT allows one foot (0.3 m) of water above the top of the inlet.
3. Select an inlet size that results in a flow depth less than or equal to the allowable. Inlet control nomographs from FHWA's "Hydraulic Design of Highway Culverts" (HDS No. 5) can be used for this.
4. Select a barrel size and slope that results in the barrel flowing less than full. Select a slope steep enough to maintain supercritical flow. Charts in FHWA's "Design Charts for Open-Channel Flow" (HDS No. 3) have been developed from Manning's equation and can be used to select the appropriate slope.
5. Determine the drop, Z, needed for the slope section. The minimum drop needed is the specific energy at the inlet (H_1) minus the specific energy at the barrel (H_2) plus energy losses (H_L). Specific energy is the depth plus velocity head at a given location. The hydraulic principles for round pipe are the same as described in the section for slope tapered box culverts. Although the appearance of the Design Graph for pipe culverts is different, the calculations are similar.

The following guidelines, chart and worksheet (English units only) are provided to assist in the hydraulic design.

When the inlet will be raised significantly to create a pond, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive.

Guidelines

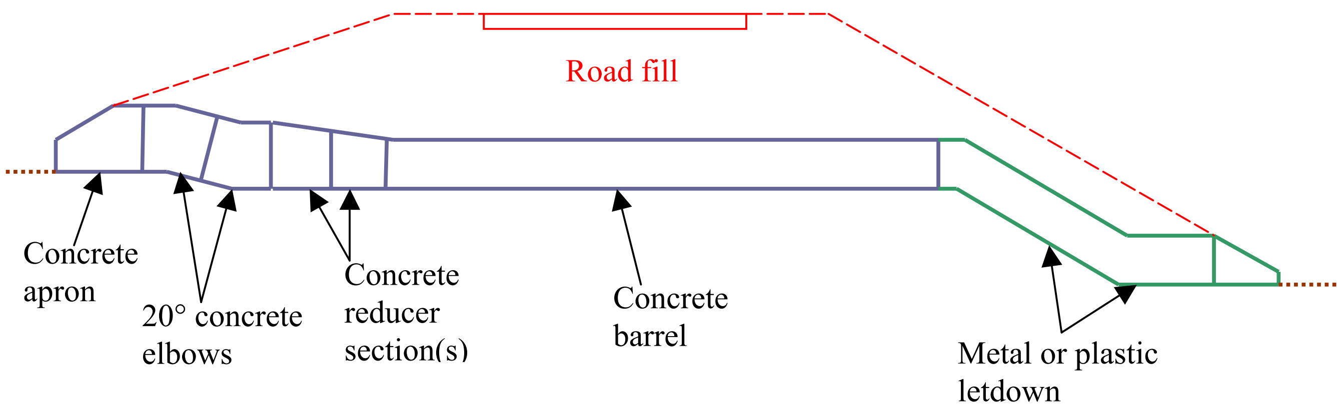
Some of the following guidelines were verified by hydraulic research in 1997 at FHWA's Turner-Fairbank Highway Research Center in Virginia and funded by the Iowa Highway Research Board, HR-398.

1. Use only the reductions in diameter listed in the table. Any variations to this table should be verified with detailed hydraulic calculations.
2. In order to maintain supercritical velocities in the concrete barrel, use the minimum slope or steeper as shown in the table. This assumes a depth of flow of 0.8 x D and an n-value of 0.012. If the discharge, slope or desired depth of flow vary from these assumptions, use FHWA's Design Charts for Open-Channel Flow, HDS No. 3, to determine the minimum slope.
3. Concrete pipe reducers are available in four-foot long sections with six inches of diameter reduction per section. For example, if reducing pipe diameter by 12 inches, two reducer sections are needed, resulting in an eight foot length of pipe.
4. For simplicity, design both concrete elbows at 20° each which is approximately a 3:1 slope.
5. The 20° elbows end-to-end will give a vertical drop, Z, of approximately 2.1 feet (0.64 meters). If greater drop is needed as determined in the design calculations, a four-foot long section of standard pipe could be installed between the two elbows. This results in a drop of approximately 3.5 feet (1.07 meters).
6. Pipe outlets larger than a 48-inch diameter will generally need a cast-in-place reinforced concrete flume rather than a metal or polyethylene letdown pipe.

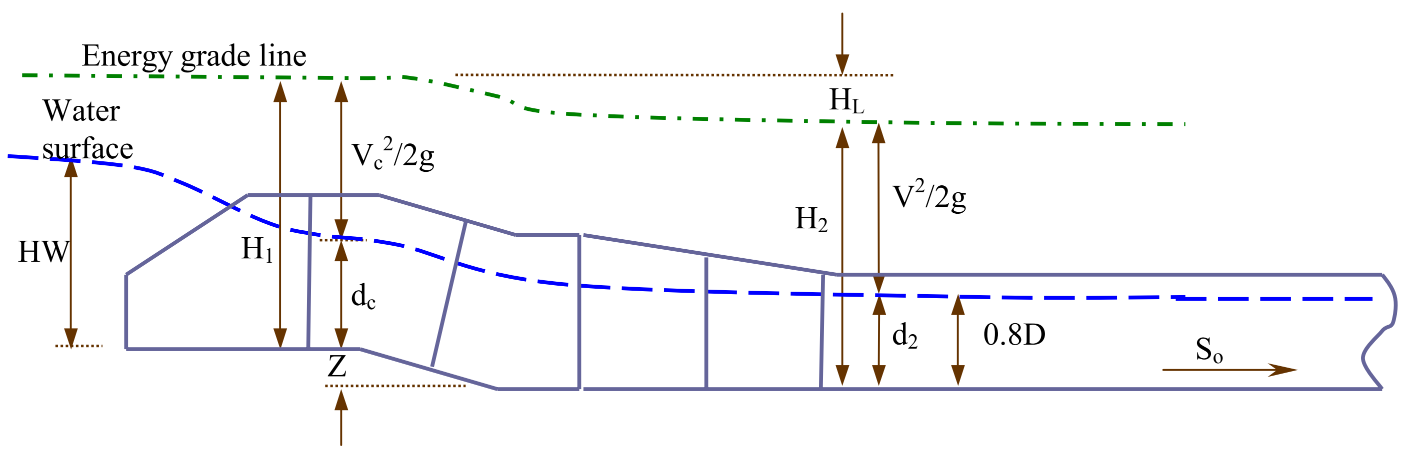
	Diameter Reduction, inches (mm)			
Approx. Q, ft^3/sec (m^3/sec)	**From**	**To**	**Vertical Drop (Z), feet (m)**	**Minimum Barrel Slope, %**
350 (9.9)	84 (2100)	72 (1800)	2.1 (0.64)	0.8
350 (9.9)	84 (2100)	66 (1650)	2.1 (0.64)	1.1
295 (8.4)	78 (1950)	66 (1650)	2.1 (0.64)	1.0
295 (8.4)	78 (1950)	60 (1500)	3.5 (1.07)	1.3
245 (6.9)	72 (1800)	60 (1500)	2.1 (0.64)	1.0
245 (6.9)	72 (1800)	54 (1350)	3.5 (1.07)	1.6
200 (5.7)	66 (1650)	54 (1350)	2.1 (0.64)	1.2
200 (5.7)	66 (1650)	48 (1200)	3.5 (1.07)	2.0
160 (4.5)	60 (1500)	54 (1350)	2.1 (0.64)	0.9
160 (4.5)	60 (1500)	48 (1200)	2.1 (0.64)	1.5
125 (3.5)	54 (1350)	48 (1200)	2.1 (0.64)	1.0
125 (3.5)	54 (1350)	42 (1050)	2.1 (0.64)	1.7
96 (2.7)	48 (1200)	42 (1050)	2.1 (0.64)	1.2
96 (2.7)	48 (1200)	36 (900)	2.1 (0.64)	2.0
71 (2.0)	42 (1050)	36 (900)	2.1 (0.64)	1.3
50 (1.4)	36 (900)	30 (750)	2.1 (0.64)	1.6
33 (0.93)	30 (750)	24 (600)	2.1 (0.64)	2.0

Slope Tapered Pipe Culverts

Modified Type 1501 Letdown

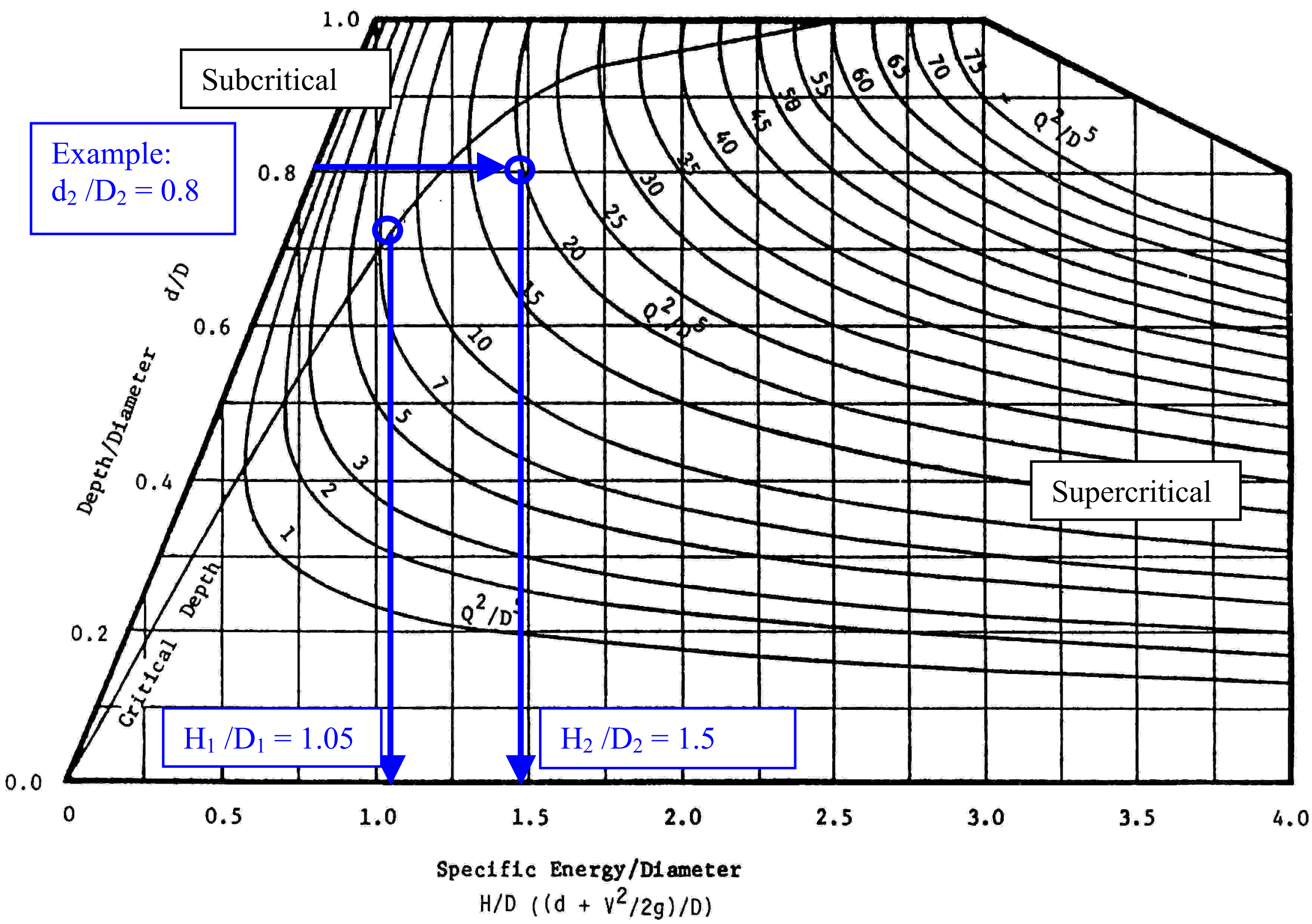


Hydraulic Performance



Design Graph for Slope Tapered Pipe Culverts

Specific Energy Curves for Circular Pipe



May 2, 1997

Worksheet for Slope Tapered Pipe Culverts (English)

Project_____________________ County________________ Sta._______________

Designer__________________ Date____________________

Variable	Example	Trial 1	Trial 2	Trial 3
Design Q , ft^3/s	250			
Inlet Section				
D_1 , ft (size of inlet)	6.0			
HW, ft (HDS #5)	7.1			
Q_1^2 / D_1^5	8.0			
d_c / D_1 (from Chart)	0.72			
H_1 / D_1 (from Chart)	1.05			
d_c , ft	4.3			
H_1 , ft	6.3			
Barrel Section				
D_2, ft (size of barrel)	5.0			
Q^2 / D_2^5	20.0			
d_n/D_2 = 0.8 (Design max. depth)	0.8	0.8	0.8	0.8
H_2 / D_2 (from chart)	1.50			
H_2 , ft	7.5			
Slope Tapered Section				
H_L, ft (assumed)	0.2	0.2	0.2	0.2
Z, ft (= $H_2 - H_1 + H_L$)	1.4			
Selected Z , ft	2.0			
Barrel Slope				
d_n , ft (= 0.8 X D_2)	4.5			
Min. Barrel Slope, % (table)	1.1			
Is the design acceptable?	Yes			